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Decision Tree for Lead-Based Paint Hazard Control and Abatement for Steel Structures

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Foreword

This technology demonstration was conducted for Headquarters, Department of the Army under Program Element (PE) 063728A, "Environmental Technology Demonstration"; Project 002, "Environmental Compliance Technology"; Work Unit CF-M B101, "Cost-effective Technologies to Reduce, Characterize, Dispose, or Reuse Sources of Lead Hazards." Bryan Nix, ACSIM-FDF, was the Technical Monitor.

The work was performed by the Materials and Structures Branch (CF-M) of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Dr. Ashok Kumar. Part of this work was done by Timothy D. Race, Corrosion Control Consultants and Labs, Inc., Elmhurst, IL, under contract no. DACA-42-02-P-0070. The technical editor was Gordon L. Cohen, Information Technology Laboratory – Champaign. Martin J. Savoie is Chief, CEERD-CF-M, and L. Michael Golish is Chief, CEERD-CF. The Technical Director of the Installation Operations Business Area is Gary W. Schanche (CEERD-CV-T), and the Director of CERL is Dr. Alan W. Moore.

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1 Introduction

Background

The estimated surface area of steel structures at Army facilities such as water tanks, bridges, aircraft hangars, antennas, ladders, poles, railings, catwalks, metal buildings, etc., is approximately 50 million square feet. About 80% of this steel is coated with red lead oxide primer to protect it from corrosion.

Many options are available for the management and removal of lead-based paint (LBP) on steel structures. Typical approaches to LBP hazard control and abatement include *in-place management* using overcoatings such as moisture-cured polyurethane; *removal* through use of technologies such as abrasive media blasting, chemical stabilizers (e.g., Blastox®, Pretox®, and Lead-X®), water jetting, HEPA*-filtered vacuum-shrouded power tools, environmentally acceptable chemical strippers, thermal spray vitrification, and laser blasting; and *judicious neglect* followed by demolition and recycling of the steel. The waste generated by any of these strategies is often hazardous due to the toxicity and leaching characteristics of lead. A means of selecting the best available strategy for a given structure is necessary in order to balance cost, worker health, and government environmental objectives.

Objective

The objective of this research was to develop a decision tree (i.e., decision support tool) to help responsible personnel or contractors to select the best available strategies for LBP hazard control and abatement for steel structures.

* HEPA: high efficiency particulate air.

Approach

Three major categories of LBP management strategies were identified and analyzed in terms of applicability, risk, and cost/benefit issues:

- paint replacement
- overcoating
- maintenance avoidance.

Details and implications of these strategies are discussed in Chapter 2.

In order to develop the decision-support tool, key evaluative criteria to be used in the decision-making process first had to be identified. The key criteria were determined to be:

- economic life of the structure
- severity of exposure
- overcoating-related risk
- condition of existing coating and substrate
- environmental sensitivity
- complexity of structure.

These criteria are explained at some length in Chapter 3.

The criteria were used as the basis for developing the decision-support tool, a *decision tree*. This tool is designed to help typical personnel in the field to quickly identify the most advisable LPB management strategy for any structure as well as a short list of appropriate techniques for executing the strategy.

The 'user interface' of the decision tree, presented in Chapter 4, is a checklist with the evaluative criteria restated in the form of eight yes / no questions. Not only the questions, but the order in which they are asked, are essential to proper use of the decision tree. By answering the questions in order, the user proceeds through a simple process of elimination that identifies the most highly recommended LBP management strategy for any given application.

Scope

This research addressed Department of Defense (DoD) Compliance Category 8, "Decontamination of Structural Facilities," and Army Environmental Quality Require-

ment Statements: Compliance A (2.3.k), "Cost-effective Technologies to Remove, Characterize, and Dispose or Reuse Sources of Lead Hazards," Ranking 9.

The results of this work are applicable to steel structures coated with lead based paint.

Mode of Technology Transfer

The following modes of technology transfer are underway:

1. a technology transfer plan being administered through the Army Environmental Center (AEC)
2. publication for potential Army users in Public Works Technical Bulletin (PWTB) 420-70-2, *Installation Lead Hazard Management*
3. representation in user groups and committees such as the Army Lead and Asbestos Hazard Management Team, Federal Lead-Based Paint Committee meetings at the Environmental Protection Agency, the Department of Housing and Urban Development, and the ASTM D01.46 Industrial and Protective Coatings Committee
4. Army 6.3-funded demonstration and validation of related emerging technologies now underway and continuing through Fiscal Year 2003; and cost / performance reports documenting the results of those activities.

Dissemination of information related to this topic is supported through several Army-supported web sites, including the following:

- http://www.hqda.army.mil/acsimweb/fd/policy/facengcur.htm, maintained by the Army Assistant Chief of Staff for Installation Management (ACSIM)
- http://www.hqda.army.mil/acsimweb/fd/policy/host/index.htm, maintained by ACSIM for the Hands-On Skill Training (HOST) program
- http://aec.army.mil/usaec/, maintained by the U.S. Army Environmental Center (USAEC)
- http://www.cecer.army.mil/td/tips/index.cfm, maintained by ERDC/CERL.

Units of Weight and Measure

U.S. standard units of measure are used throughout this report. A table of conversion factors for Standard International (SI) units is provided below.

SI conversion factors		
1 in.	=	2.54 cm
1 mil	=	0.00254 cm
1 ft	=	0.305 m
1 sq in.	=	6.452 cm^2
1 sq ft	=	0.093 m^2
1 lb	=	0.453 kg
1 psi	=	6.89 kPa

2 Review of Strategies

Introduction

The three LBP management strategies considered in this study were:

- paint replacement
- overcoating
- maintenance avoidance.

Each LBP management strategy is defined and discussed in terms of productivity, waste generation, pollution potential, worker exposure, technological risk, and standardization. Also presented are specific methods or technologies employed to execute each strategy.

Paint Replacement

Overview

The strategy referred to here as *paint replacement* is synonymous with *industrial deleading*. This strategy involves using one or more methods to completely remove all LBP from the steel structure or component. The uncoated steel is then repainted with a lead-free coating system.

The paint replacement strategy eliminates the environmental liability associated with the continued presence of LBP. This strategy represents the lowest degree of technological and financial risk. Technological and financial risks are low because the economic life of paint replacement is consistently high and the incidence rate of premature failure is low. The replacement coating will have a longer economic life than either the overcoating or maintenance avoidance strategies.

Paint replacement involves the potential for pollution through the release of lead-containing materials to the land, air, and water. Available environmental control technologies are adequate to mitigate the potential for significant environmental releases. However, some paint removal technologies have a higher inherent poten-

tial for releases in cases where environmental controls may fail. Therefore, pollution risk is highly variable, and is dependent on both the removal technology and the environmental controls or process containment used. Environmental controls vary from minimal to high for the paint replacement strategy. Environmental risk is generally higher for this strategy than for overcoating or maintenance avoidance.

The quantity and characteristics of the waste generated is dependent on the LBP removal technology. Some technologies are designed to eliminate the hazardous characteristic while other methods reduce total quantities of waste. Some technologies do not address the characteristics or amount of waste but provide economic benefits by reducing worker protection requirements or improving productivity.

The required degree of worker protection is also a function of the paint removal technology. Methods producing particulate dust generally require more rigorous worker protection than methods that produce no dust. Methods that collect dust at the point of generation may require reduced levels of worker protection. Levels of worker protection vary from low to high for this LBP management strategy.

Productivity (i.e., rate of paint removal) is dependent on the paint removal technology utilized. High-energy particle or water impingement methods generally have the highest productivity. Environmental controls that collect debris at the point of generation will reduce overall productivity. Productivity ranges from low to high depending removal technology.

Industry standards have been established for some (but not all) paint removal technologies. These standards address removal methods, materials, and the quality of the prepared surface. Standardization of environmental controls is sufficient to address all removal methods.

Specific paint removal technologies may have other inherent limitations or advantages. Some removal methods are not able to physically alter the substrate to produce either a profile or remove tightly adherent mill scale. This limitation may effectively eliminate some technologies from consideration in specific circumstances. Mobilization and capital costs are also important considerations. Removal methods that require extensive mobilization of removal and environmental control equipment may not be cost-effective for relatively small jobs. The capital investment represented by this equipment also may be significant and may not be economical for small projects. Some paint removal methods and environmental controls are of limited effectiveness depending on the form and complexity of the coated structure.

Coating removal technologies include mechanical, wet, chemical, and combinations thereof. Available methods are presented in detail below.

Abrasive Blasting

Open-nozzle dry abrasive blast cleaning can be used to produce a high-quality lead-free surface. The specified level of surface preparation will dictate the level of cleanliness, with SSPC-SP 6, SP-10, and SP 5 all appropriate for deleading projects.

A variety of blast media types can be used, including single-use expendable abrasives and multiple-use recyclable abrasives. Waste volume generated using expendable abrasives is high while waste from recyclable abrasives is low to moderate. Worker exposure and pollution potential are high because dry abrasive blasting produces large volumes of dust. Rigorous environmental controls are required to contain the dust and debris generated. Containment of the process results in extremely high airborne lead concentrations, and ventilation is required to reduce worker exposures down to a level where respirators are effective. The productivity of abrasive blast cleaning techniques is high.

Chemical Stabilizers

Chemical stabilizers are sometimes used in conjunction with open-nozzle dry abrasive blasting and wet abrasive blasting to eliminate the hazardous characteristic of the waste. Stabilizers can either be blended with an expendable abrasive blast media such as coal slag or can be painted onto the lead-bearing surface. The blast additive adds material cost and the topical paint stabilizer adds material and labor costs. However, overall costs are reduced through elimination of the hazardous characteristic of the waste, which reduces the cost of paint waste disposal, handling, and storage. There is some financial risk involved because the products are not 100% effective. Chemical stabilizers have little or no impact on paint removal productivity. They do not reduce the potential for pollution or lower worker exposure.

Vacuum and Centrifugal Blast Cleaning

These methods are variations on dry abrasive blast cleaning, and they can be used to produce a high-quality lead-free surface. SSPC-SP 6 is an appropriate cleanliness standard for vacuum blasting, and SP 6, SP 10, or SP 5 can be specified for centrifugal blast cleaning. Vacuum blasting employs a vacuum shroud to collect dust and debris at the point of generation. Centrifugal blast machines use high-speed bladed wheels to hurl abrasive at the substrate. These automated or semi-automated machines also collect dust and debris under vacuum. Vacuum and cen-

trifugal blast methods typically utilize recyclable abrasive media and produce low to moderate volumes of waste. Worker exposures and pollution potential are low. Centrifugal blast machines have high productivity while vacuum blasting has low productivity. Neither method can be used on irregular surfaces or complex structures.

Power Tool Cleaning

Paint replacement is selected most often when the coating condition is poor and the substrate is rusted or bears mill scale (i.e., Condition G as depicted by SSPC-VIS 3, "Visual Standard for Power- and Hand-Tool Cleaned Steel"). Using power tools, this coating / substrate condition can be deleaded and prepared for repainting if SSPC-SP 11, "Power Tool Cleaning to Bare Metal," is specified. Power tools such as rotary flaps, needle guns, and disk grinders can be used to achieve the SP 11 condition.

Power tool cleaning productivity is low. The method fractures and disperses the paint, and as such worker protection requirements are moderate to high. The volume of waste produced and the potential exposure to the environment are low. Worker and environmental protection can be enhanced with little effect on productivity by employing vacuum shrouds to collect paint debris at the point of generation. However, vacuum shrouds are ineffective on irregular or complex surfaces such as lattice work.

Wet Abrasive Blasting

Wet abrasive methods include water-injected abrasive blast cleaning and abrasive-injected water blast cleaning. The water serves primarily to reduce dust generation; worker exposures are low to moderate, but pollution potential is still high. Waste volumes are moderate to high. Productivity is high for water-injected methods, and moderate to high for the abrasive-injected method. Quality of surface preparation is excellent for water-injected methods and good to excellent for the abrasive-injected method. Corrosion inhibitors are generally required to prevent flash rusting of the prepared surface. Wastewater should be filtered and recycled. Appropriate levels of surface preparation to specify with this technology are SP 6, SP 10, and SP 5. The methods are discussed in detail in Joint Technical Report SSPC-TR 2 / NACE 6G198, "Wet Abrasive Blast Cleaning."

Water Jetting

Water jetting processes and surface cleanliness standards are presented Joint Surface Preparation Standard SSPC-SP 12 / NACE No. 5, "Surface Preparation and

Cleaning of Steel and Other Hard Materials by High- and Ultrahigh-Pressure Water Jetting Prior to Recoating." High-pressure water jetting (HPWJ) is cleaning performed at pressures from 70 to 170 MPa (10,000 to 25,000 psi). Ultrahigh-pressure water jetting (UHPWJ) is cleaning performed at pressures above 170 MPa (25,000 psi). SP 12 surface cleanliness levels WJ 1, WJ 2, and WJ 3 are appropriate standards to use in conjunction with this strategy and method. Interim Guide to SSPC-VIS 4(I) / NACE No. 7 depicts these levels of cleanliness in a series of photographs. The standard and photographs also describe levels of flash rusting. Permissible levels of flash rusting to use with this technology and strategy are none, light, or moderate.

The quality of surface preparation using HPWJ is moderate to good and productivity is moderate. The level of worker exposure is low to moderate and the pollution potential is moderate to high. The waste volume can range from low to high, and depends on the whether water is recycled and cleaned.

The quality of surface preparation using UHPWJ is moderate to excellent and productivity is high. The level of worker exposure is low to moderate and pollution potential is moderate to high. Waste volume can range form low to high, and depends on the whether water is recycled and cleaned. UHPWJ uses less water than HPWJ.

Water jetting can also be performed using a vacuum shroud to collect the water and paint debris at the point of generation. The quality of surface preparation using HPWJ or UHPWJ with a vacuum shroud is moderate to excellent, but productivity is low. The level of worker exposure is low and the pollution potential is low. The waste volume can range form low to high, and again depends on the whether water is recycled and cleaned. Vacuum-shrouded water jetting is not practical for irregular surfaces or complex shaped structures.

Water jetting does not produce a surface profile and therefore it may not be an appropriate surface preparation method for previously painted mill scale-bearing surfaces where the new coating system will require a profiled surface.

Chemical Stripping

In this method, alkaline or solvent-based strippers are applied by trowel, brush, roller, or spray. After a specified dwell time the stripper and paint are removed by scraping and/or water cleaning. There is no standard for specifying chemical stripping or levels of surface cleanliness. In some cases it may be possible to specify surface cleanliness using SSPC VIS standards for blast, power tool, or water jet cleaned surfaces. Chemical strippers do not remove rust or mill scale and cannot create a

profile. They often leave a thin residue of old paint on the surface, however, this is not a problem if the stripped surface is repainted with a surface tolerant coating system. Chemical strippers are only moderately effective on complex structures.

Productivity is low by most estimates, especially at low temperatures (i.e., less than 60 °F). The quality of surface preparation is dependent on the condition of the underlying steel, and ranges from poor to excellent. Surface quality can be enhanced if chemical stripping is used in conjunction with other technologies such as power tool cleaning. Worker exposure and pollution potential are low. The volume of waste generated is low to moderate. Some conventional chemical strippers may exhibit the hazardous characteristic for corrosivity, flammability, or toxicity. 'Environmentally friendly' or 'environmentally acceptable' chemical strippers are also available (e.g., alcohol hydrocarboxylic acid-hydrogen peroxide-based strippers and N-methyl pyrrolidone-based products), however, their production rates tend to be lower than the currently used chemical strippers (e.g. those based on caustics or hazardous solvents). One newly available chemical stripper containing a chemical stabilizer is said to be effective at eliminating the hazardous lead characteristic.*

Nontraditional Abrasives

Examples of nontraditional abrasives are sodium bicarbonate, carbon dioxide, ice crystals, and sponge media. Nontraditional abrasive media require specialized equipment. The quality of surface preparation can vary from poor to excellent. Productivity is low to moderate. Worker exposures are low to moderate. Pollution potential is high. Volume of waste generated is typically low. SP 6, SP 10, and SP 5 can be specified for sponge media. Depending on the substrate condition, the lowest level of abrasive blasting surface cleanliness recommended for deleading jobs, SP 6, may or may not be achievable using other nontraditional media.

Emerging Technologies

In addition to the lead hazard control and abatement technologies described above, users should consider various emerging technologies that have recently come to the market. Personnel responsible for lead hazard control and abatement also should keep abreast of nontraditional emerging technologies. However, users should thoroughly research previous applications and perform a pilot abatement demonstration

* Back To Nature, Dynacraft Industries, Inc., Englishtown, NJ 07726.

before full-scale implementation of any emerging technology. After reviewing all options and considering the advantages and disadvantages of each, the user should select the most effective technology for the given application.

Thermal Spray Vitrification

The thermal spray vitrification (TSV) process removes and encapsulates LBP in a single operation wherein powdered glass is melted and sprayed onto the painted surface. Heat degrades the coating and lead is drawn into the molten glass matrix. Adherent glass is readily removed with hand tools. Multiple applications may be necessary to remove all of the LBP. Secondary remelting or treatment of the vitreous waste product may or may not be necessary to fully encapsulate the lead and eliminate the hazardous characteristic. The fully treated paint waste can be disposed of as nonhazardous. No containment structure is required because the process produces no hazardous lead dust effluents. Only minimal worker protection equipment is required.

TSV technology is available from a limited number of commercial vendors. It has proven to be useful for niche applications, such as removal of lead-based paint from fire hydrants. Tyndall AFB, FL successfully used this procedure to remove lead-based paint from over 300 fire hydrants in 1998 – 1999. Other niche applications include zone painting on large bridge structures or on small fixed structures, such as pump casings, where the cost of the containment structure required for conventional technologies would be a large part of the overall cost. Available documentation indicates that productivity is 35 sq ft / hour on flat areas. The potential for pollution is low. Worker exposure can range from low to high and is dependent both on operational parameters and lead content of the coating being removed.

The process does not remove tightly adherent mill scale or create a profile, although a previously existing profile may be recovered so that the substrate is suitable for repainting. Thin-section steel (e.g., less 0.0625 inch thick) may be warped by the heat produced by the applicator unless it is cooled by mist. There are no existing standards that describe the process or materials used. The end condition of the steel cannot be described using existing standards.

Laser Blasting and Xenon Flash Lamp / Carbon Dioxide Blast

These novel methods have been investigated by the Department of Defense (DoD) for use on aircraft. These are not currently available for use as deleading tools on industrial structures, but depending on their success and cost-effectiveness, they may become commercially available for wider application in the future.

Summary of Removal Technologies

Table 1 summarizes the types of paint removal technologies that may be utilized as part of the paint replacement strategy.

Table 1. Paint removal technologies.

Method	Standards	Productivity	Waste Volume	Worker Protection	Pollution Potential	Profile Creation
Abrasive Blast – Expendable Media	SP 6, 10, 5	High	High	High	High	Yes
Abrasive Blast – Recyclable Media	SP 6, 10, 5	High	Low to Moderate	High	High	Yes
Vacuum Blast	SP 6	Low	Low to Moderate	Low	Low	Yes
Centrifugal Blast	SP 6, 10, 5	High	Low to Moderate	Low	Low	Yes
Power Tool	SP 11	Low	Low	Moderate to High	Low	Yes
Power Tool – Vacuum Shrouded	SP 11	Low	Low	Low	Low	Yes
Abrasive Blast – Water Injected	SP 6, 10, 5	High	Moderate to High	Low to Moderate	High	Yes
Water Blast – Abrasive Injected	SP 6, 10, 5	Moderate	Moderate to High	Low to Moderate	High	Yes
High Pressure Water Jetting	SP 12 (WJ 1, 2, or 3)	Moderate	Low to High	Low to Moderate	Moderate to High	No
Ultra High Pressure Water Jetting	SP 12 (WJ 1, 2, or 3)	High	Low to High	Low to Moderate	Moderate to High	No
Water Jetting – Vacuum Shrouded	SP 12 (WJ 1, 2, or 3)	Moderate to High	Low to High	Low	Low	No
Chemical Strippers	No Standard	Low	Low to Moderate	Low	Low	No
Sponge Blast	SP 6, 10, 5	Low to Moderate	Low	Low to Moderate	Moderate	Yes
Thermal Spray Vitrification	No Standard	Low	Low	Low to High	Low	No

Overcoating

Overview

Overcoating may be defined as the practice of painting over existing coatings as a means of extending service life. Maintenance painting of this type does not require extensive surface preparation. Overcoating can be significantly less expensive than

other maintenance practices, particularly when the existing coating contains lead or other hazardous materials.

Productivity rates for overcoating are generally high because surface preparation requirements are minimal. Waste generation is generally quite low as is the potential for significant worker exposures to lead. Pollution potential is also minimal; ground tarps or screens for debris collection are typically the only pollution control method required. In some cases, though wash water collection may be necessary.

Industry standards for overcoating do not exist, but the Army has developed risk-assessment criteria for overcoating. The Army also has evaluated various overcoating materials and surface preparation techniques (Race 1998, 2000a, 2000b, 2001).

Risk Issues

Overcoating is performed with a significant degree of risk. As used in this report, the term *risk* refers to the degree of probability that the overcoated system may either fail catastrophically or will not provide protection for the intended service life.

In many cases overcoating has been used inappropriately by the industry. Because of the potentially large initial cost savings, overcoating appears to be highly attractive compared to alternatives requiring LBP containment and removal. The large initial cost difference between these maintenance options has led some owners to be somewhat tolerant of the risks involved in overcoating. Nevertheless, it is important for owners to conduct a valid risk assessment before selecting overcoating as the method of choice. Even if overcoating risks are deemed acceptable, the facility owner must still take proper steps to mitigate those risks.

The primary risk associated with overcoating is that the coating system will delaminate. If a delamination failure occurs, then the overcoating investment is lost. Delamination of LPB may also represent an environmental hazard, and in such a case the risk of litigation is very real. Additionally, the remediation costs arising from the introduction of lead into the environment may be significant. Delamination is difficult to predict, but an understanding of the underlying principles should help the coatings engineer prevent or reduce the risk of a delamination failure.

Delamination is primarily the result of internal stresses in the overcoat material that cannot be supported by the underlying (aged) coating. Internal stress occurs as the applied overcoat contracts, either from solvent evaporation or curing. Several factors affect the degree of internal stress in the overcoat material, including type of coating, formulation, and film-forming conditions. As coatings age, film stress gen-

erally increases. Aging may result in additional cross-linking and film shrinkage. A good example of age related stress increase is the oxidative curing of alkyds. Temperature fluctuations may also affect the level of internal stress, with higher temperatures favoring lower stress and colder temperatures causing higher stress. The higher stress associated with cold temperatures is the major cause of overcoat system failure by delamination. Also, plasticizer migration may lead to reduced elasticity or embrittlement of both aged coatings and overcoats, and brittle coatings are more likely to crack during thermal cycling. The application of the overcoat may also affect the internal stress of the aged coating. Solvent migration may initially reduce the stress in the existing coating but subsequent solvent evaporation will result in a net increase in the film stress. Resin in the overcoat material may penetrate the aged paint, forming a stress zone within the old coating.

The internal stress of the overcoat is counteracted by its adhesion to the aged coating. A loss of adhesion of the aged coating to the substrate may result in cracking of the overcoat because internal stress is no longer supported by the underlying coating. This is true when the internal stress of the overcoat exceeds its tear strength. When the tensile stress in the overcoat exceeds that in the aged coating and the overcoat cracks, then peeling and delamination are likely to occur. Good overcoat / basecoat systems, like all multi-coat systems, should have higher tensile strength and rigidity in the basecoat than in the topcoat. New coating systems should specifically be designed this way, and overcoat / basecoat systems also should be designed this way. However, in practice it is difficult to ensure that the stress of the overcoat will not overwhelm the adhesion of the old existing coating.

The other primary risk associated with overcoating is that the overcoat system will not provide a long enough service life to be considered cost-effective. In this case the overcoat system may not experience a catastrophic failure such as delamination, but may fail prematurely because of the severity of the service environment or the degree of protection expected of the overcoat material. Such failures are typified by early onset of corrosion or excessive rust-through.

Thicker aged coatings tend to be more highly stressed. Large peeling forces can be generated during curing and aging of the overcoat. Therefore, when overcoated, thicker coatings are more likely to delaminate than thinner ones. Delamination may also be caused by thermal cycling, which may disrupt the integrity of thick aged coatings that have been overcoated. Thicker coatings are also more likely to sustain blast media damage or other mechanically induced damage, resulting in a subsequent loss of adhesion that may affect overcoat system performance.

The mechanical properties of coatings may change as they age. Age-related changes are due primarily to changes within the coating that increase the glass transition temperature. As a coating's glass transition temperature increases, its internal stress increases, adhesion decreases, and brittleness increases. The glass transition temperature increase is generally the result of thermal and photo radiation effects. For acrylic latex coatings it has been shown that the increase is due entirely to photo radiation. For oil paint the effect is mainly due to photo radiation, and for alkyd the effect is caused by both thermal and photo radiation, with thermal effects playing a greater role. Long oil coatings generally take longer to embrittle than short oil coatings.

Epoxy and alkyd coatings may chalk and erode with prolonged exposure. Generally this does not present a problem for overcoating as long as the loose chalk is removed prior to painting. Even severely eroded coatings with exposed primer may be good candidates for overcoating if the remaining coating has good adhesion and total rusting is nominal.

The degree of adhesion of the aged coating to the substrates is one of the most critical factors affecting the overcoating process. Poorly adherent coatings are more likely to delaminate when overcoated than are aged coatings with good adhesion. Poor intercoat adhesion in aged multi-coat systems may also result in overcoat delamination failures. The aged coating system will generally fail at its weakest point. Coating type, age, thickness, and surface preparation may all affect the adhesion of the aged coating system.

The condition of the substrate may also affect the performance of the overcoat system. As a general rule, the more corrosion present, the more surface preparation will be needed. Mechanical cleaning, especially abrasive blasting, may disrupt the adhesion of the aged coating adjacent to the removal areas. Additionally, overcoating may not be cost-effective if extensive surface preparation is required. The quality of original surface preparation may also play a role in the performance of the overcoat to the extent that it affects coating adhesion on mill scale and other poorly cleaned surfaces. This may cause localized problems on structures that were not cleaned uniformly prior to receiving the original coating.

The problems associated with surface contaminants are not necessarily specific to overcoating, but contaminants are less likely to be removed during overcoating because much less surface preparation is typically done. Less surface preparation is performed in order to reduce costs, environmental hazards, and worker exposure to hazardous dusts. Rigorous surface preparation is generally avoided because it often

causes mechanical damage to an old, marginally adherent embrittled coating, and this damage may later manifest itself as a delamination failure.

As noted previously, thermal- and photo radiation-induced increases in the glass transition temperature may lead to embrittlement and reduced adhesion of an aged coating. Oil and oil modified alkyds on structural components exposed to thermal and photo radiation will be most vulnerable to these age-related effects. Similar coatings in protected areas that are not directly exposed to the sun, however, may be suitable for overcoating. Thermal cycling is another weather-related effect. Internal coating stresses can increase to unsupportable levels at low temperatures, and this explains why many overcoat delamination failures occur during or after cold spells. Structures in mild climates are less likely to be exposed to low temperatures that may precipitate delamination failures. Conversely oil and alkyd coatings exposed in sunny climes may age faster than in other locales.

Cost/Benefit Issues

Hazardous coatings are generally removed using abrasive blasting or by water jetting. Containment and disposal of surface preparation debris, worker protection, and other regulatory compliance costs combine to make removal of hazardous paints very expensive. According to a Federal Highway Administration (FHWA) report, bridge maintenance painting costs have nearly doubled over the past 5 years. Typical bridge maintenance painting contracts involving complete coating removal and repainting averaged $5.05 / sq ft for nonhazardous coatings and $10.60 / sq ft for hazardous paint removal. The added costs for worker health, environmental monitoring, waste disposal, and containment are significant. The FHWA study concluded that for mild service environments overcoating is more cost-effective than other maintenance options on a life cycle cost basis. FHWA research has shown that for severe service environments, such as immersion, and chemical and marine atmospheres, total removal and replacement of the aged coating with a high performance coating system is more cost-effective than overcoating (Kogler, Ault, and Farschon 1997).

A life-cycle cost comparison between overcoating and paint replacement was performed for Corps of Engineers civil works structures. The results of that comparison study indicated that overcoating in a mild exposure environment is always less expensive than paint replacement (Race 2000b). The study also concluded that (1) overcoating is never economically viable in a severe exposure and (2) overcoating may or may not be more economical in a moderate exposure environment.

Maintenance Avoidance

Overview

Maintenance avoidance, as the term implies, is a strategy wherein maintenance of the LBP-coated steel is avoided; no paint maintenance is performed for the remaining economic life of the structure. The economic life of the structure can be limited by either its physical, mission, or technological life. The maintenance avoidance strategy includes disposal of the structure, which may consist of demolition, demolition with whole structure replacement, or partial demolition with steel replacement.

The demolition phase of this strategy implies a degree of worker exposure, environmental risk, and waste production. Worker and environmental exposures may occur during rivet busting and flame cutting of lead-coated steel. Paint removal prior to flame cutting is another potential mode of worker and environmental exposure. Waste generation is minimal because the amounts of paint removed are comparatively small. At the current time, this type of construction debris is not classifiable as a hazardous waste in most localities. However, the U.S. Environmental Protection Agency (EPA) is reviewing the potential hazards associated with construction debris, and the status of such debris could change in the future.

Risk Issues

In general, maintenance avoidance offers fewer risks than active management strategies. Nevertheless, as with the active maintenance strategies there are still inherent risks. For example, unexpected changes in mission could mean that the planned disposition of a structure has to be postponed or canceled, and this in turn could lead to unexpectedly high maintenance costs. In some cases, if the paint condition is poor or the remaining economic life of the structure is long, the paint may deteriorate to the point where ground contamination becomes an issue. This, of course, is an unintended consequence of the avoidance strategy.

Cost/Benefit Issues

The economic benefit of this strategy is derived from the avoidance of paint maintenance costs that are not necessary to extend the physical life of the structure beyond mission or technological life of the structure.

3 Strategy Selection Criteria

Introduction

As stated previously, the three major strategies for dealing with lead based paint on steel structures are *paint replacement*, *overcoating*, and *maintenance avoidance*. In this chapter, a series of evaluative criteria to aid in the selection of a strategy are discussed:

- economic life of the structure
- severity of exposure
- overcoating-related risk
- condition of existing coating and substrate
- environmental sensitivity
- complexity of structure.

Differentiating between the two active maintenance strategies — paint replacement and overcoating — can be complicated. The selection process is based on the applicability of the various criteria. Depending on how the criteria apply, some of them may help to differentiate between the use of specific methods or technologies that fall under a general strategy. In some cases there may be more than one viable options for LBP management within a given strategy.

A discussion of the major criteria, and their relationship to various risk factors, is presented below. This discussion is intended to help clarify how best to allocate technological, economic, and environmental risk.

Economic Life of the Structure

The first criterion for differentiating between active maintenance (paint replacement or overcoating) and maintenance avoidance is the economic life of the structure. Economic life will be limited by the structure's mission life, technological life, and physical life. If the physical life of the structure without paint maintenance will be longer than the mission or technological lives, then the maintenance avoidance will always be the most cost-effective approach. If the mission and technologi-

cal lives are both longer than the expected physical life of the structure, then an economic assessment is needed to evaluate the cost-effectiveness of maintenance avoidance versus active maintenance.

Physical Life

A structure's physical life is defined as the period of time during which it or one of its components retains its robustness or functionality. When the structure degrades beyond a certain point, it can no longer be maintained economically and it is less costly to replace it than to repair it. If a structure is already near the end of its physical life, then it may be more economical to avoid maintaining the paint. In some cases it may not be the LBP-coated steel, but another portion of the structure, that is limiting the overall structural life. Again, it makes little sense to perform expensive LBP removal or overcoating if the structure is nearing the end of its physical life. If the physical life is the limiting criterion, then an economic analysis must be performed to assess whether it is more cost-effective to maintain the LBP-coated steel or not.

Mission Life

The mission life of a structure is the period of time for which the structure is needed to accomplish the mission. Mission requirements change over time, and as a result some durable infrastructure may no longer needed. For example, an aviation mission may be moved from an installation, eliminating need for onsite aviation fuel storage tanks. Another example is the closure of an installation, in which case it may be more economical to avoid maintenance altogether. If mission life is the limiting criterion, then no economic analysis is necessary and the maintenance avoidance strategy is cost-justified.

Technological Life

The end point in the technological life of a structure is the point at which it becomes technologically obsolete. A structure is considered obsolete it must be replaced in order to continue supporting the mission. If technological life is the limiting criterion, then an economic analysis is unnecessary and the strategy of maintenance avoidance is cost-justified.

Estimating Economic Life

Mission life and technological life can usually be inferred from long-range planning documents for any facility or major command. Physical life is much harder to esti-

mate and typically requires a detailed condition assessment or a base of knowledge that is adequate to predict the physical life. The interrelationships among these three types of life cycles ultimately determines the economic life of a structure.

Severity of Exposure

The severity of the exposure environment will affect the cost-effectiveness of paint removal versus overcoating. According to an FHWA study, overcoating is always more cost-effective in a mild exposure environment and repainting is always more cost-effective in a severe exposure environment (Kogler, Ault, and Farschon 1997). An economic assessment is required for moderate exposure environments to determine the more cost-effective strategy except where overcoating is advisable either because the structure is complex or the location is environmentally sensitive.

Normal interior and exterior atmospheric exposures fall into the *mild exposure* category. Marine coastal and industrial atmospheres, as well as interior and exterior pipes and vessels subject to frequent condensation, fall into the category of *moderate exposure*. Marine/industrial, heavy industrial, and chemical atmospheres are considered to be *severe exposure*, as are all types of immersion applications. SSPC: The Society for Protective Coatings has a system for defining and classifying various types of exposures, which are referred to as *environmental zones*.

SSPC Environmental Zones 2A and 2B are frequently wet by fresh water and salt water, respectively. These exposures involve condensation, splash, spray, or frequent immersion. Condensation in this case is either continuous or nearly continuous. Salt water environments may include bridges, docks, piers, and platforms over salt water. Coastal structures within 250 meters of the shoreline may also meet the definition, especially when prevailing winds come from offshore. Environmental Zones 2C and 2D are fresh water and salt water immersion, respectively. In general, overcoating should not be considered for SSPC Environmental Zones 2A, 2B, 2C, or 2D.

Overcoating should definitely not be performed on structures or components exposed in SSPC Environmental Zones 3A (chemical, acidic), 3B (chemical, neutral), 3C (chemical, alkaline), 3D (chemical, solvent), and 3E (chemical, severe). In general, industrial atmospheres may or may not meet the definition of zone 3A (pH 2.0 – 5.0). Structures in industrial atmospheres that fall outside of the definition of Environmental Zones 3A – 3E may be considered as candidates for overcoating. Mild industrial atmospheres are typical of most industrialized cities in the United States. However, certain industrialized areas in the United States as well as devel-

oping industrial nations are quite severe, typically meeting the criteria for Environmental Zones 3A – 3E, so steel structures in these areas should not be overcoated.

SSPC Environmental Zones 1A (interior, normally dry) and 1B (exterior, normally dry) are considered acceptable for overcoating. Most structures or components generally fall into one of these categories. Zone 1B is typified by normal rainfall and atmospheric temperatures. Bridges on which de-icing salts are used typically are considered to be Zone 1B exposures. In practice, however, portions of these bridges should be classified as Zone 2B. Surfaces in Zone 2B can be successfully overcoated, but in general it is more cost-effective to perform total removal and repainting with a high-performance coating system.

Overcoating-Related Risk

The overall risk expected to arise from overcoating is a criterion used to differentiate between the paint replacement and overcoating strategies. Where the risk is moderate to high or failure is certain, paint replacement is the preferred strategy.

Techniques for Assessing Risk From Overcoating

Techniques for assessing risk associated with overcoating include physical inspection and application of a test patch followed by a post-inspection after a specified time period. Visual inspection is the most rapid and least expensive means of assessing a structure to determine the appropriateness of the overcoating strategy. Visual inspection supplies a nominal amount of information, including a general assessment of the extent, nature, and location of corrosion. A physical inspection requires direct access to the coated surfaces. It supplies useful information about film thickness and adhesion. A patch test supplies the most definitive information of any assessment technique. At its completion the engineer should know to a high degree of certainty whether the proposed combination of surface preparation and overcoat material will perform.

Physical Assessment Techniques

A physical inspection of the structure and aged coating system should be conducted to determine the paint film thickness, adhesion, and presence of mill scale. The most rapid method of measuring paint adhesion is ASTM D 3359, *Standard Test Methods for Measuring Adhesion by Tape Test*. ASTM D 3359 employs a sharp blade, which is used to scribe through the coating to the substrate. Method A em-

ploys an X-shaped scribe and is used for paint films thicker than 5.0 mils. Method B calls for a series of cuts in a crosshatch pattern, and is used for relatively thin film coatings. The specified tape is applied to and removed from the scribed area and the adhesion is rated based on the amount of paint removed from the substrate. In practice, Method A is almost always used when assessing coating adhesion in the field. The adhesion should be measured at a minimum of five random locations on each type of representative component identified during the visual assessment. For large components or structures a minimum of 5 measurements per 10,000 sq ft should be performed.

The thickness of the aged paint system should be determined in accordance with SSPC PA-2, *Measurement of Dry Paint Thickness with Magnetic Gages*. Dry film thickness should be measured for each representative component of the structure. Film thickness may be categorized as thin (0 < 10 mils), medium (10 – 20 mils), or thick (> 20 mils).

The presence of mill scale is tested by removing a small area of coating. The aged coating can be removed using chemical stripper or by abrading the coating. A saturated copper sulfate solution is then applied to the steel surface. If the substrate is mild steel, copper will plate out on the surface and form a copper-colored deposit. Surfaces covered with mill scale will turn black or not exhibit a change of appearance. The mill scale determination should be made on each type of representative component identified during the visual assessment. For large components or structures a minimum of three tests per 10,000 sq ft should be performed.

Patch Testing

One or more test patches should be applied to judge the risk associated with overcoating a particular structure. Surfaces and components representative of the structure should be tested. The condition of areas to be evaluated should be assessed using the visual and physical inspection techniques. Cleaning, surface preparation, and overcoat materials should be identical to those proposed for use on the structure. The overcoat materials should be applied to the prepared test areas, re-inspected after cure, and reevaluated using the visual and physical inspection techniques. The test patches are re-inspected after short-term (14 days) or long-term (6 months minimum) curing. Ideally the test exposure period should span at least one winter season. The degree of rusting (ASTM D 610) and adhesion (ASTM D 3359) should be determined at a minimum of five spots on each test patch at the conclusion of testing.

Acceptance Criteria for Overcoating

Table 2 contains criteria for assessing the risk associated with overcoating based on film thickness and adhesion of the existing coating. The criteria are based on the principle that the risk of failure increases with increasing film thickness and decreasing adhesion. Risk is categorized as NONE (essentially no risk), LOW, MODERATE, HIGH, and CERTAIN (failure likely). Risk refers to the degree of probability that the coating will fail catastrophically by delamination. The maximum level of risk that should be accepted on projects using these criteria is LOW.

Table 2. Risk-based acceptance criteria — coating thickness and adhesion.

Adhesion (ASTM D 3359)	Coating Thickness		
	Thin (<10 mils)	Medium (10-20 mils)	Thick (>20 mils)
5A or 5B	NONE	NONE	NONE
4A or 4B	NONE	NONE	NONE
3A or 3B	NONE	NONE	LOW
2A or 2B	LOW	LOW	MODERATE
1A or 1B	MODERATE	HIGH	HIGH
0A or 0B	CERTAIN	CERTAIN	CERTAIN

Table 3 contains criteria for assessing the risk associated with overcoating based on film thickness and adhesion of the existing coating on substrates covered with mill scale. The criteria are based on the principle that the risk of failure increases in presence of mill scale. Risk is categorized as NONE (essentially no risk), LOW, MODERATE, HIGH, and CERTAIN (failure likely). As before, the maximum level of risk that should be accepted on projects using these criteria is LOW.

Table 3. Risk-based acceptance criteria for surfaces bearing mill scale.

Adhesion (ASTM D 3359)	Coating Thickness		
	Thin (<10 mils)	Medium (10-20 mils)	Thick (>20 mils)
5A or 5B	LOW	LOW	LOW
4A or 4B	LOW	LOW	LOW
3A or 3B	LOW	LOW	MODERATE
2A or 2B	MODERATE	MODERATE	HIGH
1A or 1B	HIGH	CERTAIN	CERTAIN
0A or 0B	CERTAIN	CERTAIN	CERTAIN

Patch test results are relatively easy to interpret. Delaminated test patches imply high risk or certain failure. An intermediate level of risk is indicated by poor or reduced levels of intercoat and/or base-coat adhesion, as determined at the conclusion of testing. Signs of early rusting or blistering may also indicate a measured degree of risk associated with overcoating. Other warning signs include wrinkling, mud-

cracking, lifting, and peeling. Table 4 summarizes risk-based acceptance criteria for patch testing; the maximum acceptable level of risk for most projects is LOW.

Table 4. Risk-based acceptance criteria for patch testing.

Post-Cure Adhesion (Short and Long Term Cure) D 3359	Post-Cure Rusting (Long Term Cure) D 610	Post-Cure Film Defects (Short and Long Term Cure)
NONE = 5A, 4A, 3A LOW = 2A MODERATE = 1A CERTAIN = 0A	NONE = 9 or 10 LOW = 8 MODERATE = 7 HIGH = 6 CERTAIN = 5 or less	MODERATE = Wrinkling and cracking HIGH = Peeling and lifting CERTAIN = Blistering and delamination

Coating and Substrate Condition

Degree of Rusting

The degree of rusting is one aspect of this criterion. It is applied to separate the overcoating and paint replacement strategies based on the extent of rusting (i.e., corrosion) observed on the structure. A high degree of rusting does not necessarily mean the technological risk of overcoating is unacceptable. However, overcoating becomes less cost-effective when more rust is present.

A quantitative visual inspection of the aged coating system should be conducted to determine the extent and degree of rusting. Rusting should be rated on a scale of 0 – 10 as described in ASTM D 610, *Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces.* ASTM D 610 is supplemented by a series of color photographs depicting various degrees of rust. Representative components and areas of a structure should be visually evaluated according to the following steps:

1. Conduct a general survey of the structure to identify representative components of the structure. For example, the representative components of a water tank might include the outer shell, roof, ladders, and piping. The service environment of each component should be identified.
2. Identify areas with typical levels of coating degradation and rusting for each type of component.
3. Identify areas that show a much greater level of degradation than the typical areas. The types of components or structural characteristics that correspond with these areas should be noted.
4. Evaluate the degree of rusting on representative typical and worse-than-typical areas.

Rusting levels of 10% (ASTM D 610 rust rating of 4) for typically degraded areas and 17% (ASTM D 610 rust rating of 3) for the most severely degraded portions of a structure are the maximum recommended for the overcoating strategy. If the degree of rusting is greater, it is considered to be severe; the work necessary to clean and paint severely corroded structures approaches the level required for complete removal and replacement. Furthermore, the performance of an overcoat system applied over a severely degraded substrate is likely to be inferior to the performance of a new paint system applied over blast-cleaned steel.

Profile of Underlying Steel

The other aspect of the 'condition' criterion is substrate profile. It is applied to select among paint removal methods that produce a surface profile on steel that has no profile. In cases where the substrate has no profile (e.g., it was never abrasive-blasted or it bears mill scale), the performance of new paint will be enhanced through use of a surface preparation method that produces a profile. Methods that produce a profile include all of the wet and dry abrasive blasting methods as well as power tool cleaning to bare metal (SP 11).

Environmental Sensitivity of Location

The environmental sensitivity criterion is used to distinguish between types of paint removal technologies and, in some cases, between paint replacement and overcoating. In moderate exposures conditions where both overcoating and paint replacement are technically viable strategies, overcoating is clearly more cost-effective than recoating if the location is environmentally sensitive.

Some paint removal methods create large amounts of airborne lead-containing dust while others do not. Environmentally sensitive locations are at risk when paint removal methods that have a high potential for pollution are used. In most cases, dust-producing surface preparation methods are safe because the processes are contained in a way that provides adequate protection to the environment and public health. However, in certain circumstances containment or equipment may not perform as intended, unintentionally releasing hazardous lead dust into the environment. If a very sensitive receptor is close to the point of release, then that receptor may be negatively impacted by a release of lead dust. Examples of very sensitive receptors include residences, schools, uncontrolled public access points, and special natural habitats. Employee access areas are not generally considered sensitive receptors because employee exposures are regulated in a different manner.

The environmental sensitivity criterion is applied whenever there is a very sensitive receptor within 50 ft (horizontal distance) of the point of potential release and the release height is less than 25 ft. This approach is conservative and is consistent with the findings of an environmental assessment performed for the Triborough Bridge and Tunnel Authority (2002). Note that this criterion can be considered flexible. In some cases the specifier may choose to be more or less stringent. It should also be noted that this criterion may be applied to a portion of a structure (versus the entire structure). This flexibility can be important because the cost of managing LBP mitigation near environmentally sensitive receptors is significant.

Complexity of Structure

The structural complexity criterion is applied to distinguish between various types of paint removal methods in terms of environmental soundness and cost-effectiveness when used on complex structures or substrates.

Paint removal methods employing vacuum shrouds are generally ineffective on complex structures. Directed methods, including wet and dry abrasive blasting, are generally preferred for complex structures.

In a moderate exposure conditions where both overcoating and paint replacement are technically viable strategies, overcoating is clearly more cost-effective than re-coating if the structure is complex.

Complex structures are characterized by bolted and riveted connections, small beams, small pipes, lattice work, and angles. By contrast simple structures have broad flat surfaces, welded connections, and larger beams and pipes. An example of a complex structure is an old truss-type bridge with lattice work and riveted connections. An example of a simple structure is a ground water storage tank.

4 Decision Tree

Introduction

Decision trees can be useful tools for selecting the best from among several possible courses of action. A decision tree is a representation of a decision process wherein solutions are systematically determined for a specific set of circumstances. The decision tree method employed here is known as *binary recursive partitioning*. The process is binary because each parent node on the tree is split into two child nodes. The process is recursive because each successive child node is treated as a parent node until the node terminates in a solution. The methodology used here asks questions that can be answered by responding either yes or no. Terminating nodes provide recommended strategies; in some cases the user is advised to perform an economic analysis as a means of choosing the more cost-effective of competing strategies. The cost-effectiveness test is applied only when the decision tree yields two technically viable strategies with similar costs that cannot be differentiated without a detailed economic assessment.

Note: The technologies considered in this decision tree are proven, established technologies that are available through multiple vendors and that are documented with cost and performance data collected over many years in varying applications. Emerging technologies are *not* considered in the current decision tree. However, as these technologies mature and become more cost-effective, they should be introduced as viable alternatives. For example, for a particular lead-removal application at Tyndall Air Force Base, FL (see page 17), TSV paint removal technology was determined to be sufficiently mature and more cost-effective compared to any conventional lead abatement technology.

Description of the Decision Tree

Evaluative Criteria Expressed as Queries

The decision tree for LBP hazard control and abatement on steel structures employs up to eight questions to the user. These queries are based on the evaluative criteria

described in Chapter 3, and by answering the questions systematically the user can arrive at a recommended solution for a given set of circumstances. However, each question and answer is laden with specific technical meaning, so the user must be knowledgeable about steel structures and coatings. The user also must have accurate information about the location, configuration, condition, and economic life of the particular structure. The quality of the decision can only be as good as the information gathered before the decision tree query process.

The eight queries incorporated into the decision tree are:

1. Is the mission life or technological life shorter than the physical life of the structure?
2. Is the exposure environment severe?
3. Is the risk of overcoating either moderate or high?
4. Is the degree of rusting severe?
5. Is the exposure environment mild?
6. Is the location environmentally sensitive?
7. Is the structure complex?
8. Is there an existing blast profile?

Each of these queries arises from one of the general criteria discussed in Chapter 3.

Output Solutions

The query process provides eight possible outputs or solutions. One output selects maintenance avoidance as the best strategy. Five of the outputs encompass the range of available paint replacement technologies. One output selects overcoating as the best strategy and one selects either overcoating or paint replacement as the best strategies. All of the active maintenance outcomes require further analysis by the user to produce the optimal strategy from two possible solutions (i.e., active maintenance versus maintenance avoidance). These competing outputs are not readily refinable within the context of the decision tree. The output decisions are discussed in detail below.

Maintenance Avoidance

This output is selected when queries (1) and (2) are both answered yes. Maintenance avoidance is the best strategy in these cases because the structure will either be technologically obsolete or the mission requirement will lapse before the structure reaches the end of its physical life.

Economic Assessment of Maintenance Avoidance versus Overcoating and Paint Replacement

This output is selected when both overcoating and paint replacement are technically viable and economically competitive (i.e., the location is not environmentally sensitive and the structure is not complex).

Economic Assessment of Overcoating versus Maintenance Avoidance

This output is selected when overcoating is certain to be more cost-effective than paint replacement, e.g., when overcoating -related risk is low, the exposure is mild, and the degree of rusting is not severe. The output is also selected when overcoating risk is low, degree of rusting is not severe, and exposure condition is moderate while the structure is complex or the location is environmentally sensitive.

Economic Assessment of Maintenance Avoidance versus Paint Replacement

There are five separate variations on this output decision. In each case an economic assessment must be performed comparing paint replacement to maintenance avoidance. In some cases more than one type of paint replacement or removal technology is presented as viable. These paint removal alternatives should generally be considered not as specifier options but as contractor options. These decision tree outputs also instruct the specifier to select from available surface cleanliness standards and containment levels. The surface preparation standards are joint SSPC and NACE standards. The containment levels are those presented in SSPC-Guide 6, *Guide for Containing Debris Generated During Paint Removal Operations*. These inputs are needed in order to conduct the economic assessment and to properly specify the performance requirement of the paint replacement strategy.

The five variations under this output decision are:

1. *Power Tool Clean versus Maintenance Avoidance.* This option is selected when the query process directs the specifier to the replacement strategy, in other words when exposure is severe, overcoating risk is moderate or high, or the location is environmentally sensitive. Additionally the structure must be complex. Power tool cleaning will be performed in accordance with SSPC-SP 11. The contractor option should be either vacuum-shrouded power tools used with ground covers and/or hanging tarps, or power tools with Class 1P containment.

2. *Vacuum Blast, Chemical Strip, or Power Tool Clean versus Maintenance Avoidance.* This option is selected when the query process directs the specifier to the

replacement strategy, i.e., when the exposure is severe, the risk associated with overcoating is moderate or high, or the location is environmentally sensitive. Also the structure must not be complex, and the substrate must have a blast profile. Contractor options should be vacuum blast to SP 6 with ground covers and/or hanging tarps; chemical strip to remove all paint with Class 1C containment; power tool clean to SP 11 with Class 1P containment; or vacuum-shrouded power tool clean to SP 11 with ground covers and/or hanging tarps.

3. *Power Tool Clean or Vacuum Blast versus Maintenance Avoidance.* Again, this option is selected when the query process directs the specifier to the replacement strategy, in other words when the exposure is severe, the overcoating risk is moderate or high, or the location is environmentally sensitive. Also the structure must not be complex and the substrate must not have a blast profile. The absence of a blast profile eliminates chemical stripping as a viable option. Contractor options should be vacuum blast to SP 6 with ground covers and/or hanging tarps; power tool clean to SP 11 with Class 1P containment; or vacuum-shrouded power tool clean to SP 11 with ground covers and/or hanging tarps.

4. *Water Jet or Abrasive Blast versus Maintenance Avoidance.* This option is selected when the query process directs the specifier to the replacement strategy because either the exposure is severe or the overcoating risk is moderate or high. Additionally, the location is not environmentally sensitive, the structure is not complex, and the substrate has a blast profile. Contractor options are water jetting to SP 12 with Class W containment or abrasive blasting with Class A containment. The specifier should indicate the level of containment (1, 2, or 3) and degree of surface cleanliness (SP 12 conditions WJ1, WJ2, or WJ3; or SP 6, SP 10, or SP 5). Abrasive blast as used here means that the contractor may use recyclable media, expendable media, blast media stabilizers, sponge media, water-injected abrasive blasting, or abrasive-injected water blasting. For wet abrasive methods and water jetting. the specifier should also indicate an acceptable level of flash rusting as depicted in Interim Guide to SSPC-VIS 4 (I) / NACE No. 7, *Visual Reference Photographs for Steel Cleaned by Water Jetting.*

5. *Abrasive Blast versus Maintenance Avoidance.* This option is selected when the query process directs the specifier to the replacement strategy because either the exposure is severe or the risk of overcoating is moderate or high. Additionally, the location must not be environmentally sensitive, the structure may be complex or not complex, and the substrate has no blast profile. The specifier should indicate the level of containment (1A, 2A, or 3A) and degree of surface cleanliness (SP 6, SP 10, or SP 5). Abrasive blast as used here means that the contractor may use recyclable media, expendable media, blast media stabilizers, sponge media,

water-injected abrasive blasting, or abrasive-injected water blasting. For wet abrasive methods the specifier also should indicate an acceptable level of flash rusting as depicted in Interim Guide to SSPC-VIS 4 (I) / NACE No. 7, *Visual Reference Photographs for Steel Cleaned by Water Jetting.*

Graphical Presentation of the Decision Tree

Because of the complexity and size of the tree, individual branches are shown separately, from the first parent node to the final output. A total of 24 branches are illustrated. Table 5 summarizes the 24 branches of the decision tree.

Branch 1

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = Yes
Decision = Maintenance avoidance is the best strategy.

Branch 2

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = No
Q3. Is the risk of overcoating moderate or high?
Value = No
Q4. Is the degree of rusting severe?
Value = No
Q5. Is the exposure mild?
Value = No
Q6. Is the location environmentally sensitive?
Value = No
Q7. Is the structure complex?
Value = No
Q8. Is there an existing blast profile?
Value = No
Decision = Conduct an economic assessment comparing paint removal by abrasive blasting, overcoating, and maintenance avoidance.

Branch 3

Q1. Is the mission life or the technological life shorter than the physical life of the structure?	Value = No
Q2. Is the exposure environment severe?	Value = No
Q3. Is the risk of overcoating moderate or high?	Value = No
Q4. Is the degree of rusting severe?	Value = No
Q5. Is the exposure mild?	Value = No
Q6. Is the location environmentally sensitive?	Value = No
Q7. Is the structure complex?	Value = No
Q8. Is there an existing blast profile?	Value = Yes
Decision = Conduct an economic assessment comparing paint removal by abrasive blasting or water jetting, overcoating, and maintenance avoidance.	

Branch 4

Q1. Is the mission life or the technological life shorter than the physical life of the structure?	Value = No
Q2. Is the exposure environment severe?	Value = No
Q3. Is the risk of overcoating moderate or high?	Value = No
Q4. Is the degree of rusting severe?	Value = No
Q5. Is the exposure mild?	Value = No
Q6. Is the location environmentally sensitive?	Value = No
Q7. Is the structure complex?	Value = Yes
Decision = Conduct an economic assessment comparing overcoating and maintenance avoidance.	

Branch 5

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = No
Q3. Is the risk of overcoating moderate or high?
Value = No
Q4. Is the degree of rusting severe?
Value = No
Q5. Is the exposure mild?
Value = No
Q6. Is the location environmentally sensitive?
Value = Yes
Decision = Conduct an economic assessment comparing overcoating and maintenance avoidance.

Branch 6

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = No
Q3. Is the risk of overcoating moderate or high?
Value = No
Q4. Is the degree of rusting severe?
Value = No
Q5. Is the exposure mild?
Value = Yes
Decision = Conduct an economic assessment comparing overcoating and maintenance avoidance.

Branch 7

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = No
Q3. Is the risk of overcoating moderate or high?
Value = No
Q4. Is the degree of rusting severe?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = No
Q7. Is the structure complex?
Value = No
Q8. Is there an existing blast profile?
Value = No
Decision = Conduct an economic assessment comparing paint removal by abrasive blasting and maintenance avoidance.

Branch 8

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = No
Q3. Is the risk of overcoating moderate or high?
Value = No
Q4. Is the degree of rusting severe?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = No
Q7. Is the structure complex?
Value = No
Q8. Is there an existing blast profile?
Value = Yes
Decision = Conduct an economic assessment comparing paint removal by water jetting or abrasive blasting and maintenance avoidance.

Branch 9

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = No
Q3. Is the risk of overcoating moderate or high?
Value = No
Q4. Is the degree of rusting severe?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = No
Q7. Is the structure complex?
Value = Yes
Decision = Conduct an economic assessment comparing paint removal by abrasive blasting and maintenance avoidance.

Branch 10

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = No
Q3. Is the risk of overcoating moderate or high?
Value = No
Q4. Is the degree of rusting severe?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = Yes
Q7. Is the structure complex?
Value = No
Q8. Is there an existing blast profile?
Value = No
Decision = Conduct an economic assessment comparing paint removal by power tool cleaning or vacuum blasting and maintenance avoidance.

Branch 11

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = No
Q3. Is the risk of overcoating moderate or high?
Value = No
Q4. Is the degree of rusting severe?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = Yes
Q7. Is the structure complex?
Value = No
Q8. Is there an existing blast profile?
Value = Yes
Decision = Conduct an economic assessment comparing paint removal by power tool cleaning, chemical stripping, or vacuum blasting and maintenance avoidance.

Branch 12

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = No
Q3. Is the risk of overcoating moderate or high?
Value = No
Q4. Is the degree of rusting severe?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = Yes
Q7. Is the structure complex?
Value = Yes
Decision = Conduct an economic assessment comparing paint removal by power tool cleaning and maintenance avoidance.

Branch 13

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = No
Q3. Is the risk of overcoating moderate or high?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = No
Q7. Is the structure complex?
Value = No
Q8. Is there an existing blast profile?
Value = No
Decision = Conduct an economic assessment comparing paint removal by abrasive blasting and maintenance avoidance.

Branch 14

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = No
Q3. Is the risk of overcoating moderate or high?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = No
Q7. Is the structure complex?
Value = No
Q8. Is there an existing blast profile?
Value = Yes
Decision = Conduct an economic assessment comparing paint removal by water jetting or abrasive blasting and maintenance avoidance.

Branch 15

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = No
Q3. Is the risk of overcoating moderate or high?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = No
Q7. Is the structure complex?
Value = Yes
Decision = Conduct an economic assessment comparing paint removal by abrasive blasting and maintenance avoidance.

Branch 16

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = No
Q3. Is the risk of overcoating moderate or high?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = Yes
Q7. Is the structure complex?
Value = No
Q8. Is there an existing blast profile?
Value = No
Decision = Conduct an economic assessment comparing paint removal by power tool cleaning or vacuum blasting and maintenance avoidance.

Branch 17

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = No
Q3. Is the risk of overcoating moderate or high?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = Yes
Q7. Is the structure complex?
Value = No
Q8. Is there an existing blast profile?
Value = Yes
Decision = Conduct an economic assessment comparing paint removal by power tool cleaning, chemical stripping, or vacuum blasting and maintenance avoidance.

Branch 18

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = No
Q3. Is the risk of overcoating moderate or high?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = Yes
Q7. Is the structure complex?
Value = Yes
Decision = Conduct an economic assessment comparing paint removal by power tool cleaning and maintenance avoidance.

Branch 19

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = No
Q7. Is the structure complex?
Value = No
Q8. Is there an existing blast profile?
Value = No
Decision = Conduct an economic assessment comparing paint removal by abrasive blasting and maintenance avoidance.

Branch 20

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = No
Q7. Is the structure complex?
Value = No
Q8. Is there an existing blast profile?
Value = Yes
Decision = Conduct an economic assessment comparing paint removal by water jetting or abrasive blasting and maintenance avoidance.

Branch 21

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = No
Q7. Is the structure complex?
Value = Yes
Decision = Conduct an economic assessment comparing paint removal by abrasive blasting and maintenance avoidance.

Branch 22

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = Yes
Q7. Is the structure complex?
Value = No
Q8. Is there an existing blast profile?
Value = No
Decision = Conduct an economic assessment comparing paint removal by power tool cleaning or vacuum blasting and maintenance avoidance.

Branch 23

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = Yes
Q7. Is the structure complex?
Value = No
Q8. Is there an existing blast profile?
Value = Yes
Decision = Conduct an economic assessment comparing paint removal by power tool cleaning, chemical stripping, or vacuum blasting and maintenance avoidance.

Branch 24

Q1. Is the mission life or the technological life shorter than the physical life of the structure?
Value = No
Q2. Is the exposure environment severe?
Value = Yes
Q6. Is the location environmentally sensitive?
Value = Yes
Q7. Is the structure complex?
Value = Yes
Decision = Conduct an economic assessment comparing paint removal by power tool cleaning and maintenance avoidance.

Table 5. Summary presentation of decision tree branches.

Branch No. and Output	Numbered Queries							
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
B1. Maintenance Avoidance	Y	-	-	-	-	-	-	-
B2. AB or OC vs Maintenance Avoidance	N	N	N	N	N	N	N	N
B3. AB, WJ, or OC vs Maintenance Avoidance	N	N	N	N	N	N	N	Y
B4. OC vs Maintenance Avoidance	N	N	N	N	N	N	Y	-
B5. OC vs Maintenance Avoidance	N	N	N	N	N	Y	-	-
B6. OC vs Maintenance Avoidance	N	N	N	N	Y	-	-	-
B7. AB vs Maintenance Avoidance	N	N	N	Y	-	N	N	N
B8. WJ or AB vs Maintenance Avoidance	N	N	N	Y	-	N	N	Y
B9. AB vs Maintenance Avoidance	N	N	N	Y	-	N	Y	-
B10. PTC or VB vs Maintenance Avoidance	N	N	N	Y	-	Y	N	N
B11. PTC, CS, or VB vs Maintenance Avoidance	N	N	N	Y	-	Y	N	Y
B12. PTC vs Maintenance Avoidance	N	N	N	Y	-	Y	Y	-
B13. AB vs Maintenance Avoidance	N	N	Y	-	-	N	N	N
B14. WJ or AB vs Maintenance Avoidance	N	N	Y	-	-	N	N	Y
B15. AB vs Maintenance Avoidance	N	N	Y	-	-	N	Y	-
B16. PTC or VB vs Maintenance Avoidance	N	N	Y	-	-	Y	N	N
B17. PTC, CS, or VB vs Maintenance Avoidance	N	N	Y	-	-	Y	N	Y
B18. PTC vs Maintenance Avoidance	N	N	Y	-	-	Y	Y	-
B19. AB vs Maintenance Avoidance	N	Y	-	-	-	N	N	N
B20. WJ or AB vs Maintenance Avoidance	N	Y	-	-	-	N	N	Y
B21. AB vs Maintenance Avoidance	N	Y	-	-	-	N	Y	-
B22. PTC or VB vs Maintenance Avoidance	N	Y	-	-	-	Y	N	N
B23. PTC, CS, or VB vs Maintenance Avoidance	N	Y	-	-	-	Y	N	Y
B24. PTC vs Maintenance Avoidance	N	Y	-	-	-	Y	Y	-

Abbreviations: "B" is branch; "AB" is abrasive blast; "OC" is overcoat; "WJ" is water jet; "PTC" is power tool clean; "VB" is vacuum blast; "CS" is chemical strip.

Spreadsheet Presentation of the Decision Tree

The decision tree is easily represented in a simple query format with a standard spreadsheet program using the "logical IF" function. The spreadsheet guides the user through a series of questions, prompting the user to answer additional questions until an output decision is determined. The program workbook consists of four pages. Each page is shown separately below with the cell formulas revealed. In the black and white version presented below, italicized (rather than green) text prompts the user to continue as indicated. Bold (rather than red) text indicates a program output or decision. Yes/no (Y/N) responses are entered in the shaded boxes. Popup text is indicated by the quotation marks. The spreadsheet program provides output identical to that given by the query format summarized in Table 5. One additional question is used in the spreadsheet program: "Are the mission life and technological life known?" This query allows the user to skip ahead without knowing either the mission or technological lives of the structure.

Worksheet 1

Questions						
1 Are the mission life and technological life known?						
2 Is the mission life or technological life shorter than the physical life?						
=IF(H3="N","Go to the questions on the next page.","")						
=IF(H5="N","Go to the questions on the next page.","")						

Worksheet 2

Questions									
1 Is the exposure environment severe?									
2 Is the risk of overcoating either moderate or high?									
3 Is the degree of rusting high?									
4 Is the exposure environment mild?									
=IF(F3="Y","Go to the questions on the next page.","")									
=IF(F5="Y","Go to the questions on the next page.","")									
=IF(F7="Y","Go to the questions on the next page.","")									
=IF(F9="Y","The best strategy is overcoating or maintenance avoidance. Conduct an economic analysis to determine the more cost-effective strategy","")									
=IF(F9="N","The best strategy could be overcoating, replacement, or avoidance. Continue with page four and then conduct an economic analysis to determine the most cost-effective of the remaining strategies.","")									

Worksheet 3

Questions									
1 Is the location environmentally sensitive?									
2 Is the structure complex?									
3 Is there an existing blast profile?									

=IF(AND(F3="Y",F5="Y"),"The best strategy could be power tool cleaning or maintenance avoidance. Conduct an economic analysis to determine the best strategy.","")

=IF(AND(F3<>"Y",F5="Y"),"The best strategy could be either abrasive blasting or maintenance avoidance. Conduct an economic analysis to determine the most cost-effective strategy.","")

=IF(AND(F3="Y",F5<>"Y",F7="Y"),"The best strategy could be vacuum blast, chemical stripping, power tool cleaning, or maintenance avoidance. Perform and economic analysis to determine most cost-effective strategy.","")

=IF(AND(F3="Y",F5<>"Y",F7="N"),"The best strategy could be power tool cleaning, vacuum blast, or maintenance avoidance. Conduct an economic analysis to determine the most cost-effective strategy.","")

=IF(AND(F3<>"Y",F5<>"Y",F7="Y"),"The best strategy could be waterjetting, abrasive blasting, or maintenance avoidance. Conduct an economic analysis to determine the most cost-effective strategy.","")

Worksheet 4

Questions									
1 Is the location environmentally sensitive?									
2 Is the structure complex?									
3 Is there an existing blast profile?									
=IF(F3="Y","The best strategy could be overcoating or maintenance avoidance. Conduct an economic analysis to determine the best strategy.","")									
=IF(F5="Y","The best strategy could be overcoating or maintenance avoidance. Conduct an economic analysis to determine the best strategy.","")									
=IF(AND(F3="N",F5="N",F7="N"),"The best strategy could be abrasive blasting, overcoating, or maintenance avoidance. Perform an economic analysis to determine most cost-effective strategy.","")									
=IF(AND(F3="N",F5="N",F7="Y"),"The best strategy could be water jetting, abrasive blasting, overcoating, or maintenance avoidance. Perform an economic analysis to determine the most cost-effective strategy.","")									

The Role of Economic Analysis

The LBP decision tree as presented here does not serve as a substitute for economic analysis. In some cases where the relative economic viability of different strategies is well known and can be generalized, the tree will limit the number of available strategies. However, the most cost-effective strategy — whether active maintenance or maintenance avoidance — must ultimately be determined through economic analysis. Three generalized cost analyses are presented to illustrate the

range of possible solutions. Calculations were performed using ECONPACK 2.1.2 (USACE Engineering and Support Center, Huntsville, AL). Current dollars, end-of-year discounting, and a discount rate of 5.67% reflecting current 30-year Treasury rates were used in the analyses. In each case the mission life of a generic steel structure was assumed to be 50 years.

Analysis Example 1

Example 1 considers the costs expressed as the net present value (NPV) of removing LBP and applying a new paint system or demolishing and replacing the structure in the current fiscal year. Paint replacement is assumed to extend the physical life of the structure 10 years in a severe exposure and 20 years in a mild exposure, after which time the structure is demolished and replaced. Future maintenance for both strategies is disregarded because their maintenance intervals should be identical.

Figure 1 shows the NPV for each strategy reflecting the life extension afforded by repainting one time in both mild and severe exposures. Cost of repainting is expressed as a percentage of the cost of structure replacement. In a mild exposure environment paint replacement is more cost-effective than replacing the structure until repainting costs approach 75% of structure replacement cost. In a severe exposure environment paint replacement is more cost-effective than structure replacement only until repainting costs exceed 45% of structure replacement cost.

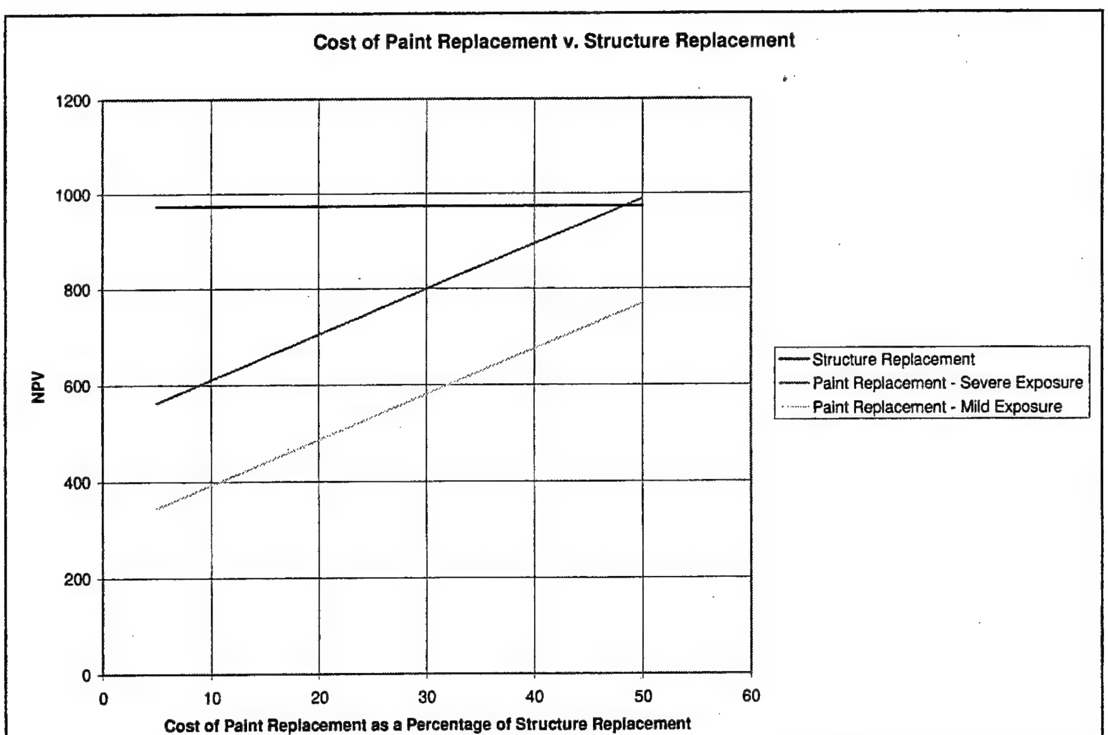

Figure 1. Cost of paint replacement versus structure replacement.

Analysis Example 2

Example 2 considers the costs expressed as the NPV of removing LBP and applying a new paint system in the current year or deferring maintenance for a period of 10 years and then replacing the structure. Paint replacement is assumed to extend the physical life of the structure 20 and 30 years in severe and mild exposures, respectively, after which time the structure is demolished and replaced. Future maintenance for both strategies is disregarded because their maintenance intervals should be identical.

Figure 2 shows the NPV for each strategy reflecting the life extension afforded by repainting one time in both mild and severe exposures. Cost of repainting is expressed as a percentage of the cost of structure replacement. In a mild exposure environment paint replacement is more cost-effective than replacing the structure until repainting costs approach 40% of structure replacement cost. In a severe exposure environment paint replacement is more cost-effective than structure replacement only until repainting costs exceed 25% of structure replacement cost.

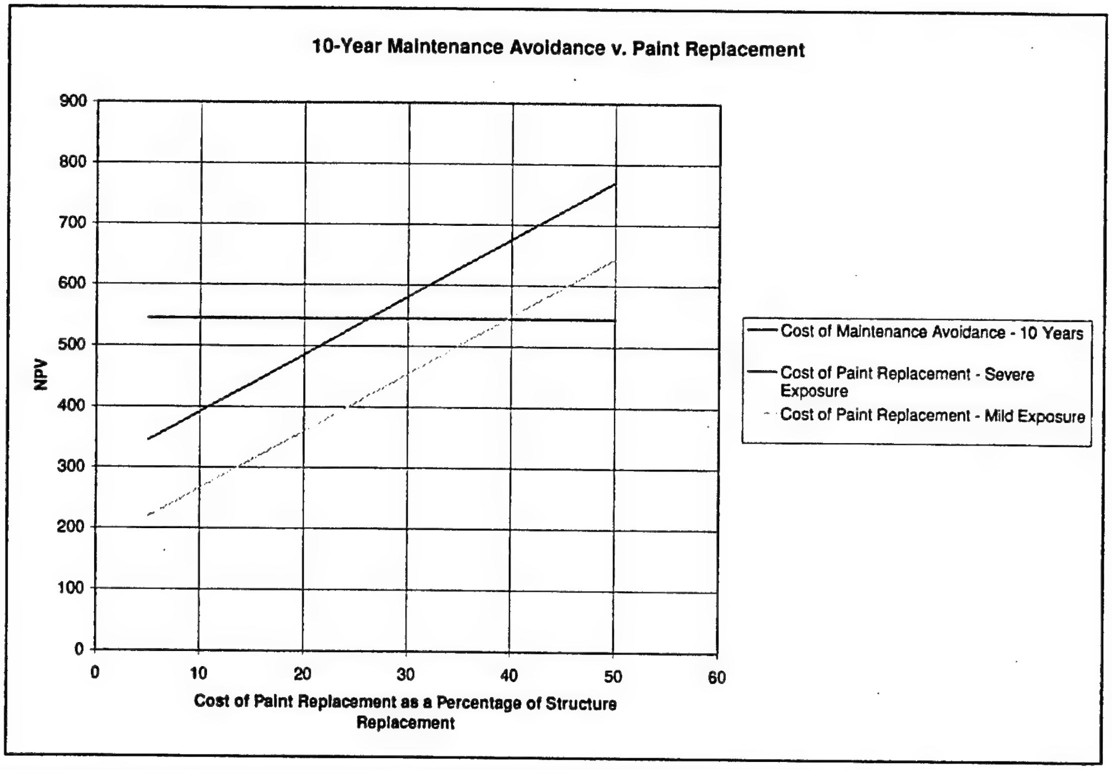

Figure 2. Cost of paint replacement versus 10-year maintenance avoidance.

Analysis Example 3

Example 3 considers the costs expressed as the NPV of removing LBP and applying a new paint system in the current year or deferring maintenance for a period of 20-

years and then replacing the structure. Paint replacement is assumed to extend the physical life of the structure 30 and 40 years in severe and mild exposures, respectively, after which time the structure is demolished and replaced. Future maintenance for both strategies is disregarded because their maintenance intervals should be identical.

Figure 3 shows the NPV for each strategy reflecting the life extension afforded by repainting one time in both mild and severe exposures. Cost of repainting is expressed as a percentage of the cost of structure replacement. In a mild exposure environment paint replacement is more cost-effective than replacing the structure only until repainting costs exceed 20% of structure replacement cost. In a severe exposure environment paint replacement is more cost-effective than structure replacement only until repainting costs approach 15% of structure replacement cost.

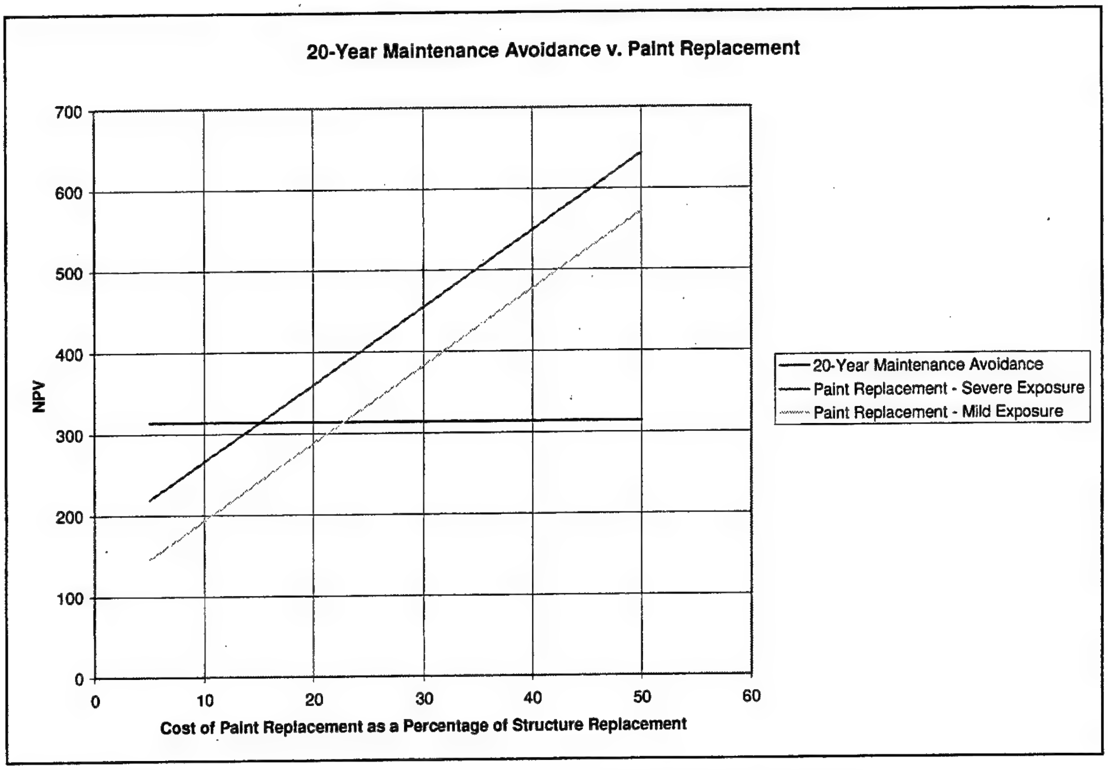

Figure 3. Cost of paint replacement versus 20-year maintenance avoidance.

5 Summary

A decision tree was developed to provide support for personnel tasked with making decisions related to LBP management for steel structures. The decision tree yields eight different outputs on 24 branches using only eight criteria. All but one output requires the user to perform an additional economic analysis to ascertain the most cost-effective decision. Outputs for paint removal and replacement include paint removal methods as well as applicable surface cleanliness and containment standards.

Successful application of the decision tree requires the user to be knowledgeable about steel structures and coatings, and to have access to specific data about the target structure and its location. In this report, the tree is presented graphically as branches showing the logic flow for each decision. The tree is also easily programmable on a desktop computer using the "logical IF" function found in standard business spreadsheet programs.

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14. ABSTRACT

Many options are available for the management and removal of lead-based paint (LBP) on steel structures. The waste generated by any of these paint removal strategies is often hazardous due to the toxicity and leaching characteristics of lead. A means of selecting the best available strategy for a given structure is necessary in order to balance cost, worker health, and government environmental objectives.

The objective of this research was to develop a decision tree to help responsible personnel to select the best available strategies for LBP hazard control and abatement for steel structures. The decision tree is implemented as a spreadsheet application that presents eight technical questions to be answered in a specified sequence. Successful application of the decision tree requires the user to be knowledgeable about steel structures and coatings, and to have access to specific data about the target structure and its location. In this report, the tree is presented graphically as branches showing the logic flow for each decision. The tree is also easily programmable on a desktop computer using the "logical IF" function found in standard business spreadsheet programs.

15. SUBJECT TERMS
lead based paint (LBP), steel structures, lead abatement, corrosion control, hazardous waste management

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